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(54) ROTOR EARTH LEAKAGE PROTECTION FOR
BRUSHLESS SYNCHRONOUS MACHINES

(71) We, BBC BROWN, BOVERI & COMPANY LIMITED of Baden, Switzerland, a Swiss Company, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

5 The invention relates to apparatus for monitoring earth leakage of the rotor circuit of a brushless synchronous machine. 5

German Auslegeschrift 1 938 222 and a British Patent specification 1 068 239 describe apparatus for earth leakage protection, but both function only when the machine rotates and the alternating current generator is energised.

10 The present invention provides an apparatus for monitoring earth leakages of the rotor circuit of a brushless synchronous machine, comprising a rotary transformer the rotor of which is mechanically coupled to the rotor of the synchronous machine, elements for detecting earth leakages mounted on the rotor of the synchronous machine, which elements 10 comprise the following circuit components:

- 15 a) the series circuit of a first fuse, a first resistor and a second fuse, the whole series circuit being in parallel with the rectified voltage at the rotor winding of the rotary transformer and being earthed at one end; 15
 b) the series circuit of a second resistor and a diode, lying between the connecting point of the first fuse to the first resistor and one end of the energising winding of the 20 synchronous machine; 20

and a control apparatus which is connected to the stator winding of the rotary transformer to receive the earth leakage information transmitted by the rotary transformer, the control apparatus further comprising means for evaluating and indicating the earth leakage information and power supply means for the control apparatus and the detecting elements 25 mounted on the rotor of the synchronous machine. The invention can provide protection for brushless motors both when the machine rotates and when it is stationary, whether the machine is energised or not energised. Furthermore the manner of working of the protective apparatus is not influenced by the capacitance to earth of the rotor winding. 25

30 The invention will now be explained in detail with reference to the accompanying drawings, showing a rotary transformer 1 and a control apparatus 33 identical with the correspondingly reference parts of Fig. 7 of our copending patent application No. 1584/76 (Serial No. 1,489,715) in which these parts are extensively described. The threshold apparatus 14 provided in the said application is however omitted and circuit elements for detecting earth 35 leakages have been substituted therefore, namely resistors R_1 and R_2 , diode D and fuses S_1 and S_2 . The brushless synchronous machine (motor or generator) is denoted by SM; its rotor is mechanically coupled to the rotor of the rotary transformer 1. EM is a three-phase generating machine, and GB a rotating rectifier bridge; the earth leakage detecting elements are preferably mounted on the support structure of this rectifier bridge. Furthermore, E is the energising rotor winding of the synchronous machine and R the protective 40 resistor provided for motors. The rotary transformer 1 has stator winding 6 and rotor winding 11. The power supply means of the control apparatus 33 includes a transformer 55 comprising a primary winding 55a and two secondary windings 55b and 55c. First rectifier means 59 are connected to the first secondary winding 55b, together with a capacitor 70 forming the DC-power supply of the control apparatus 33. Second rectifier means 60 45 connected to the second secondary winding 55c serving as power supply means for the 45

detecting elements on the rotor of the synchronous machine. For this purpose the AC-terminals of the second rectifier means 60 are connected in series to the primary winding 6 of the rotary transformer 1 and a fuse 72. Additionally there is a resistor 58 connected in parallel to the AC-terminals of said rectifier means 60. The DC-terminals of said rectifier means 60 are connected to a further capacitor 71. Third rectifier means 61 are connected to the secondary winding 11 of the rotary transformer 1. The first amplifier 56 has a base resistor 73, base-emitter resistor 74, and Zener diode 75 connected in parallel with the resistor 74. The corresponding elements of the second amplifier 57 are denoted by 76, 77 and 78. The switching-on threshold of the amplifiers 56 and 57 can be adjusted by means of the variable resistors 74 and 77, respectively. The output circuits of the amplifiers 56 and 57 comprise the relay 56a and 57a. Relay 56a controls an auxiliary relay *a* with a parallel-connected signal lamp *L*₁.

The apparatus operates as follows: When the rotor circuit of the synchronous machine SM is free of earth leakage a current $I_1 = I_3$ flows in accordance with the voltage at the rotor winding 11 of the transformer 1 and the magnitude of the resistor *R*₁. The corresponding current *I* in the stator winding 6 of the transformer 1 causes a corresponding voltage drop at the resistor 58, which by way of the rectifier 60 controls the amplifier 57 in such a manner that the relay 57a is energised to close contacts 52 whereby, by way of the normally closed contacts 53 of relay 56a, an indication is given that the apparatus is ready for operation and no earth leakage is present: lamp *L*₁ is lit and relay *a* provides a remote indication. If an earth leakage occurs at the location A of the energising winding E, a current *I*₂ flows through *R*₂ and D, and consequently $I_3 = I_1 + I_2$. The current *I* flowing in the stator winding 6 of the transformer 1 and the voltage drop at the resistor 58, therefore, increase. This voltage drop then controls the correspondingly pre-adjusted amplifier 56 in such a manner that the relay 56a is energised and closes its normally open contact 51 to indicate the earth leakage.

If the earth leakage appears not at the location A, but at a point X anywhere along the energising winding E, the voltage present at the resistor *R*₂ is equal to the sum of the voltage present at the energising winding E between the points A and X and the voltage delivered by the rectifier 61. *I*₂ is then larger than in the case of earth leakage at the point A, and in this case also the relay 56a is energised and indicates the earth leakage by way of the contact 51.

In order to avoid a thermal overload of the resistors *R*₁ and *R*₂ and the rectifier 61 at large voltage values between the points A and X, the fuses *S*₁ and *S*₂ are provided. If the current *I*₂ attains a certain value, first the fuse *S*₁ and thereafter also the fuse *S*₂ blows, the current *I*₃ in the rotor winding 11 of the transformer 1 drops to zero and thereby also the current *I*, except for the magnetising current. The two transistors 56 and 57 are cut off, and the relay 56a and 57a are de-energised. This state of the two relays again indicates an earth leakage or a defect in the fuses. It may happen that an earth leakage occurs, but subsequently however the fuse *S*₂ becomes defective for mechanical reasons. In order to prevent the earth leakage indication from disappearing again, the resistor *R*₂ is so dimensioned that the current *I*₂ flowing therein is itself sufficient to cause response of the two relays. Thus the following connection exists between the state of the relays 56a and 57a and the existence of an earth leakage as well as the state of the fuses:

Relay		State of the field winding and the fuses
56a	57a	
deenergised	energised	no earth leakage, fuses intact
energised	energised	earth leakage without or with fuses defective
deenergised	deenergised	earth leakages and/or fuses defective

During asynchronous starting of synchronous motors and asynchronous running of motors and generators relatively high voltages are induced in the rotor winding of the synchronous machine. If during such an operational state an earth leakage occurs in the rotor circuit, this voltage causes corresponding currents in the resistors *R*₁, *R*₂ and in the

rectifier 61. Again the fuses S₁ and S₂ protect these elements against damage by heating. In this case the diode limits the voltage at the rectifier 61 until the fuses have interrupted the current circuit, by blocking positive half waves of the induced voltage from passing into the rectifier 61.

The proposed invention comprises all advantageous properties such as are mentioned also in the Patent Application No. 1584/76 (Serial No. 1489715) transmission of information by means of current steps at a high power level, therefore highly reduced sensitivity to disturbing influences; transmission of information independent of the rotary speed and, particularly in the described case, no influencing by the capacities and the current of the energising winding; since the apparatus operates on the no-current principle, automatic monitoring occurs therein.

WHAT WE CLAIM IS:

1. Apparatus for monitoring earth leakages of the rotor circuit of a brushless synchronous machine, comprising a rotary transformer the rotor of which is mechanically coupled to the rotor of the synchronous machine, elements for detecting earth leakages mounted on the rotor of the synchronous machine, which elements comprise the following circuit components:

- a) the series circuit of a first fuse, a first resistor and a second fuse, the whole series circuit being in parallel with the rectified voltage at the rotor winding of the rotary transformer and being earthed at one end;
- b) the series circuit of a second resistor and a diode, lying between the connecting point of the first fuse to the first resistor and one end of the energising winding of the synchronous machine;

and a control apparatus which is connected to the stator winding of the rotary transformer to receive the earth leakage information transmitted by the rotary transformer, the control apparatus further comprising means for evaluating and indicating the earth leakage information and power supply means for the control apparatus and the detecting elements mounted on the rotor of the synchronous machine.

2. Apparatus according to claim 1, including a third resistor in the current circuit of the stator winding of the rotary transformer and forming part of the control apparatus, the voltage drop of which resistor controls by way of a rectifier, two amplifier elements in parallel, a signal relay being connected in each amplifier output circuit.

3. Apparatus according to claim 2, in which the two amplifier elements have adjustable response thresholds.

4. Apparatus according to claim 3, in which the response thresholds of the amplifier elements are so adjusted that when the rotor circuit of the synchronous machine is free of earth leakage, the voltage drop at the third resistor is sufficient to render conductive one of the two amplifier elements whereas the other amplifier element is cut off, and that upon earth leakage of the energising winding of the synchronous machine the current in the rotor winding of the rotary transformer increases in consequence of the additional earth current through the second resistor and thus also the current in the third resistor increases to such an extent that the voltage drop at this resistor is then sufficient to render the second amplifier element conductive.

5. Apparatus according to any one of claims 1 to 4, in which the second resistor is of such magnitude that the current flowing therein to earth is sufficient in itself to render responsive both amplifier elements of the relays in their output circuits.

6. Apparatus according to any of claims 1 to 5, in which the earth leakage detecting elements are mounted on the support structure of the rectifier bridge of the synchronous machine.

7. Apparatus for monitoring earth leakage of a brushless synchronous machine substantially as herein described with reference to the accompanying drawing.

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